SOME CONSIDERATIONS ON THE EFFECTS OF TEMPERATURE ON THE FOCUS OF MIRRORS, THEIR COMPENSATION AND A METHOD OF CORRECTING FOR CHANGES OF FOCUS.

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In large modern telescopes there may be considerable changes of focal length due to changes of temperature. This is particularly the case with reflectors. A spectrograph can be kept at a constant temperature and the large mirror approximately so, but not the tube of the telescope. In many cases these changes of focus interfere greatly with the quality of the photographs and attempts to correct for them by testing the focus visually cause appreciable interruptions in the exposures.

If the telescope mounting is stable (and the changes of focus not too great) they may be almost entirely allowed for without interrupting the exposures, by the use of focusing screws, which are easily worked and provided with micrometer attachments, in connection with a thermometer or two placed at critical places about the telescope, the reading of the focusing micrometers being corrected by means of a previously prepared table whenever sufficient changes in the thermometers occur. At this point it is of interest to consider some results of experience with mirrors. After the remounting of the Crossley mirror, it was used in the principal focus without any secondary reflection. The mounting proved very stable and, contrary to expectations, no changes of focus could be detected for changes of temperature up to 5½° C., altho the focus could be determined easily within 0.1 mm. The theoretical lengthening of the steel tube for a change of 5½° C. is 0.3 mm. or three times (at least) the uncertainty of determination. Such a change could hardly escape detection. It appeared, therefore, that a compensating change must have occurred in the mirror itself but no further investigations were made to determine it.

Light was thrown on the point, however, in our work here of figuring a 90 cm. flat to be used for testing the 1½ meter paraboloid for our large reflector now in construction. When approaching completion it was observed that when the temperature rose as much as ½° C. in from two to six hours (no more rapid rises were observed), the flat became sensibly *convex*. The change of focus in these tests appeared to be considerably greater than that sus-

pected in the Crossley, due perhaps in part to the fact that the flat was not silvered, and therefore absorbed the heat more rapidly than the silvered mirror. The flat became concave with falling temperature. When the changes of temperature in the optical shop were less than 0°.2 C. in four hours, the surface remained sensibly flat under our tests. Such effects of temperature on a concave mirror would be to produce changes in its focus in the same direction as those produced in the steel tube of the telescope and to tend, therefore, to compensate for such changes.

This seems to explain the behavior of the remounted Crossley telescope and is probably more or less typical of all mirrors, but differing in rapidity of change due to their size and thickness. The effect observed on the 90 cm. flat seems to have resulted largely from the difference of exposure on the two sides and on this account it seems worth while to consider the matter, for a similar effect probably results in the case of parabolic mirrors from their supporting systems in the telescopes.

In the case of a mirror freely exposed on all sides to the air one would expect a slight *shortening* of the focus with a rise of temperature due to the more rapid penetration of temperature (and consequent expansion) at the edge. The opposite occurred in the tests of the 90 cm. flat and appears to have occurred also in the Crossley paraboloid.

The 90 cm. flat rested in a horizontal position on the polishing machine, on an iron disc nearly as large as the mirror, with a layer of Brussels carpet between the mirror and the iron. The 75 cm. spherical mirror was slung a little to one side above it, in a permanent position. The changes of figure of the flat appear to be accounted for by assuming that the under side of the mirror resting on the carpet and table was thus protected against the changes of temperature to a certain extent and that in consequence the top exposed surface expanded or contracted about the lower side. This explanation seems all the more probable as no such changes of figure were observed in the spherical mirror, which was supported by an edge band and had both sides exposed to the air.* The back of the spherical mirror was polished and covered with heavy paper, shellacked on, to protect it against scratches. No tests were made with both sides of the flat exposed to the free air.

This experience seems to show that by a carefully considered

*In such tests there is no doubt as to which of the mirrors is affected.

plan for the mirror end of the telescope, it should be possible to reduce the effects of changes of temperature on the primary focus of the large mirror to a practically negligible amount.

In this connection some consideration of the construction of the telescope and exposure of the large mirror is pertinent. It has always seemed to me desirable to have the entire tube of any telescope intended for night work closed as nearly air tight as possible, except the outer end in the case of reflectors. As the effects of changes of temperature on focal length are much more pronounced in the case of reflectors, only this form of telescope will be considered in what follows.

Currents of air in a telescope tube are highly injurious to the steadiness of images and I see no advantage in trying to keep the large mirror following the changes of temperature of the external air or even of the air in the dome. The injurious effects of such currents will be greater than from the difference in temperature between a stationary column of air in front of the mirror and the air in the dome outside the telescope tube. This difference will usually be less than the unavoidable currents at the slit of the dome.*

The ideal condition would be that all parts of the telescope, particularly the mirrors and tube, be *at a constant temperature.* To my mind this can be much better approximated to, by making the lower part of the telescope tube as nearly air tight as possible. Where the guiding is to be done at the outer end of the telescope, the heat radiation from the body of the observer, especially in low temperatures, is injurious and in the case of skeleton tubes must be counteracted as far as possible. If the mirror end of the telescope is air tight and has been kept reasonably cool during the day and the outer end of the tube of the telescope covered so that the column of air inside has been imprisoned, there will be little need of ventilating the upper part of the tube, none of ventilating the region around the mirror, and little effect of convection currents during observing. Should the air in the upper part of the tube become heated during the day (which from my experience will be seldom), it may easily be replaced by cooler air before commencing observing, *if found necessary.*

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*In this connection I may say that my experience has been that the steadiness of images has been uniformly improved by keeping doors and windows of a dome tightly closed during observing, thus preventing to a large extent currents at the slit.

After the remounting of the Crossley reflector of the Lick Observatory and the construction of an observing floor slightly below the center of motion of the telescope and running gear of the dome, the mirror end of the telescope could be kept cool during the day without any special precautions other than to see that the mirror end of the telescope was turned down below the level of the observing floor. All of the windows and doors were kept carefully closed during the day as well as during the observing at night. In this way the temperature of the enclosed mass of air between the two floors had a diurnal variation of only 3° C. during bright sunny weather, whereas the temperature in the dome above the observing floor varied 11° C. The advantage of this is obvious. The same plan of having an observing floor as high as possible so that the mirror end of the telescope may extend below it into a cool mass of air during the day has been adopted for our 75 cm. telescope just finished for this observatory and for the 1½ meter reflector in construction for the mountains.

It seems best to take all the general precautions possible, such as the above, to obtain the most uniform conditions of temperature around the lower end of the telescope, without artificial means of regulation. Judging from my experience with the Crossley reflector, those will be sufficient in many cases. If upon trial of the telescope, there are still observed variations of focus, during normal observing conditions, some such attempts as the following may be made to compensate for them:

The temperatures under practically all observing conditions are *falling*. If, therefore, experiment shows that in a given telescope the focus appears to be too great after the average fall in the dome temperature, in other words that the focus of the *mirror* has *lagged* behind the shortening of the tube, then a little more rapid cooling of the mirror should counteract such an effect. This may be accomplished by increasing the protected area on the under side of the mirror or by a few small ventilating holes. The first method seems preferable. If on the contrary the focus of the mirror has shortened more rapidly than the tube it would be necessary to further protect the mirror or perhaps the entire lower end of the tube against rapid cooling. This might be done by decreasing the protected area of the lower side of the mirror.

I have made no experiments to determine whether compensations are possible for the secondary mirrors. I have no doubt,

however, that much may be done in this respect to reduce the changes of focus due to temperature effects. For instance, it would seem that polishing and silvering both front and back, exposing the back freely also, and protecting the edge, should very much reduce such injurious effects. After all of the controllable conditions have been attended to, if changes of focus still persist they should be corrected for, as a result of experiment and using thermometers as a guide, as indicated in the beginning of this article. The best positions for the thermometers should be determined for each telescope. It seems probable that no more than two positions need be observed, one near the large paraboloid, the other near the hyperboloid at the outer end of the tube for long-focus work. If the large mirror is kept at a nearly constant temperature or compensated, few or no changes of focus for work in the primary focus will be necessary. The greatest changes of focus appear to occur in the long-focus combinations and are probably due almost entirely (as we should expect them to be) to the much greater changes of temperature at the outer end of the tube.

Spectrographs will generally be kept under the control of a thermostat. If the plate or spectrograph for primary focus work is mounted on a sliding tube at the outer end of the telescope tube, all changes of focus, either of large mirror or hyperboloid, may be made by changing that sliding tube. For this purpose the focusing arrangements for that tube should be carried outside of the main tube and provided with a micrometer head.

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